Coastal Engineering Technical Note

Beach and Nearshore Survey Technology

by Larry E. Parson

PURPOSE

There will always be a need for accurate beach and nearshore survey data. Several surveying technologies are available for collecting survey data in these zones with each method having its advantages and disadvantages for specific data collection requirements. It is essential that survey specifications originate from the project's functional requirements and that survey requirements are realistic and economically attained (USACE 1996). This publication presents the most commonly used technologies in performing this type of survey and summarizes their performance capabilities and limitations. The information presented here is intended to provide engineers and scientists with the essential knowledge to select the appropriate survey technology in order to meet project requirements.

BACKGROUND

Beach and nearshore survey data are required during the life cycle of coastal projects. For example, surveys are required in order to develop shoreline change maps during preliminary planning, as input data for numerical simulations during design, to verify construction quantities, and to monitor project performance. These types of surveys are classified by USACE (1996) as engineering and construction surveys and should dictate a different surveying scope, including different accuracies, technologies, and procedures. Assembling the necessary hydrographic and nearshore survey data to support requirements for coastal projects presents special challenges. In order to address these challenges effectively, guidance is needed for planning, conducting, and evaluating coastal survey data. To date, there are no definitive industry or Federal standards designed to cover these types of survey requirements with most beach and nearshore surveying standards being based on local practice (USACE 1996). In addition, the problems associated with different end uses are made more complex by the challenges of the physical environment being surveyed. Tides, waves, and a lack of understanding of coastal processes often limit survey data accuracy and coverage. Unlike most terrestrial sites, the coastal margin changes and moves constantly, even within time frames as short as the field survey itself. To establish an accurate assessment of an entire beach system, surveys should begin on the landward side of the dune and extend seaward to depth of closure (U.S. Army Engineer Waterways Experiment Station (WES) 1995), which usually ranges between 5 and 18 m depending upon location (Dally 1993). An important component in this process is understanding and selecting the appropriate survey tools to collect data that meet project requirements and needs of data users. Guidance in this direction will be valuable in assisting planners, designers, and surveyors in reaching a common knowledge base for specifying and cost estimating survey data collection programs.

Several survey technologies are available that meet the requirements for specific projects. These technologies range from basic rod and transit methods to complex airborne platforms. Some methods directly measure topographic elevations through direct contact with the surface being surveyed, while others remotely measure water depth and must be corrected for water surface conditions such as waves and tides. Each method has its own inherent performance specifications, operational limitations, cost of operation, and special considerations.

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To establish a systematic and uniform standard for hydrographic survey functions, USACE (1994) has defined three general classes of surveys:

a. Class 1 - Survey requiring high accuracies, for example, when a precise volumetric calculation is needed for contractor payment.

b. Class 2 - Medium-accuracy requirements for applications such as project condition surveys.

c. Class 3 - Low-accuracy requirements to perform reconnaissance type surveys.

The accuracies associated with these survey classifications are addressed by USACE (1994) . The type of technology selected to survey a project will largely depend upon a combination of requirements related to data end use accuracies, spacial data density, and survey budget. Class 2 accuracy should be sufficient for surveys supporting most coastal engineering applications, with the exception of contractor payment surveys which require Class 1 accuracies (USACE 1994).

TECHNOLOGY

Included below is a summary of the most commonly used techniques for performing beach and nearshore surveys as well as some of the more recently developed high technology methods that are now available for collecting this type of data. Technologies addressed in this technical note include conventional rod and transit, survey sleds, acoustics, airborne lidar, and GPS.

I. Rod and Transit

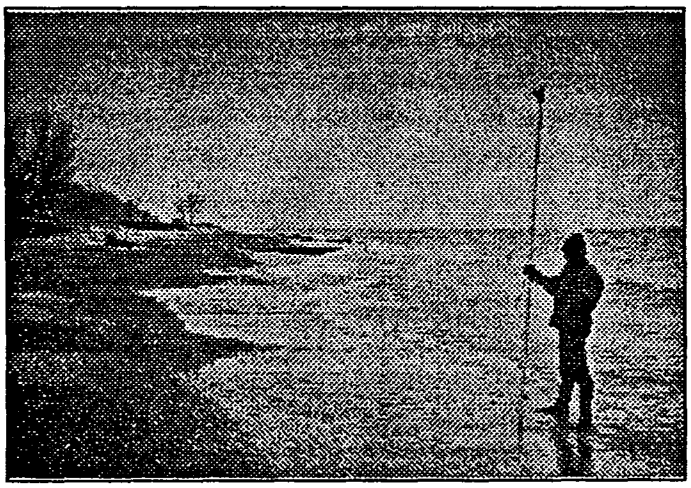

Figure 1. Rod and transit beach surveying provides accurate beach profiles to wading depth along widely spaced range lines.

Description: The rod and transit is among the most traditional and very adequate methods used in performing beach surveys. It's capable of providing highly accurate survey data. A level (or transit) and survey rod are used to directly measure surface elevation while a distance measurement is obtained using a tape or stadia producing a set of distance-elevation points along selected shore-normal lines at a specific range (Figure 1). Points are measured at regular intervals or in some cases only where there is a break in elevation. This method is typically used to collect two-dimensional cross-shore profiles spaced about 30 - 300 m (100 - 1,000 ft) apart that originates from the dune or backshore extending seaward to wading depth. Data collection does not have to be restricted to cross-shore applications. The technique can be used to establish longitudinal shoreline or dune crest positions relative to a vertical datum such as NGVD, MHW, MLW, NAVD, etc.

Surveying using the rod and transit relies on a person traversing the survey line with a survey rod and stopping at regular intervals while another team member reads and records the elevation data. The rod holder

progresses seaward until waves and water depth prevent the rod from being held steady. For this reason, it is desirable to conduct this type of survey during low tide so that the profile extends as far seaward as possible (USACE 1994). When collecting longshore measurements, data can be collected until the rod becomes too far away to obtain clear readings. Errors associated with this method typically occur as a result of human error such as incorrect stadia readings, improper instrument leveling, or inability to steady the survey rod.

Combining the use of more sophisticated equipment such as an electronic total station (ETS) can automate the process and improve positioning accuracy (Dally 1993). This method combines a distance meter with an electronic theodolite to measure distance and horizontal and vertical angles from reflective prisms on a staff. A data reader can be added to automatically record data. Data collected in this manner can be easily downloaded to a PC computer for required processing.

A more sophisticated version of this technology is the Helicopter-Borne Nearshore Survey System (HBNSS). This method is used for collecting bathymetry in extreme hazardous zones such as near coastal structures or in regions of high surf or drastically varying topography (WES 1993). The system utilizes a helicopter outfitted with a 26-m weighted, graduated cable similar to a survey rod. As the helicopter positions and lowers the weighted cable to the bottom, a shore-based surveyor's level or transit is used to read elevations. Horizontal positions are obtained using a shore-based electronic total station which tracks a cluster of prisms mounted on the helicopter. Numerous soundings are collected in this manner along predefined ranges. For more detail on this technology see WES (1993).

Performance Characteristics: (rod and transit)

Vertical accuracy:	± 1 cm to ± 10 cm
Horizontal accuracy:	3 m
Spatial resolution:	Typically shore-normal lines 300 m (1,000 ft) apart
Positioning system:	Ranging/ETS relative to established benchmarks
Minimum crew:	2
Recent costs:	About $1,000/km ($1,600/mile) of beach assuming 300-m profile spacing)

Other Considerations: Surveys performed using this method provide a cost-effective means of collecting beach data to represent general coastal trends. Inherent limitations exist with these surveying methods in that they may not produce adequate spatial resolution potentially missing information which may lead to a misinterpretation of coastal conditions. The wading portion of the survey is typically limited to calm conditions where breaker heights are less than 1 m. As the rod-man enters the surf zone, vertical accuracy quickly deteriorates (Dally 1993). In circumstances where surveys extending beyond wading depth are required, other methods and technologies should be considered. The HBNSS system is useful for collecting data around structures, especially in areas with high surf conditions. However, the cost of operating a helicopter is high and may make the collection of such a data set cost-prohibitive.

II. Survey Sled

Description: Sled survey systems were developed to collect continuous survey data from the dry beach, through the surf zone, and into the nearshore (Langley 1992). As with the rod and transit method, sled surveys provide direct elevation measurements. The system consists of a mast 10 to 11 m tall with a cluster of reflective prisms at the top. The mast is mounted to an aluminum frame sled. The sled and mast can be pulled along predetermined lines across the beach and into the nearshore by a vessel as small as an inflatable

boat to a maximum depth of about 10 m (Miller 1991). A land vehicle may be necessary for pulling the sled onto the beach from the water. As the sled is being towed, an electronic instrument such as an ETS or geodimeter (Lee and Birkemeier 1993) automatically tracks the prisms on top of the mast and records the horizontal and vertical positions at regular time intervals. Horizontal and vertical control are typically taken from existing benchmarks. This method provides a fast, portable, and economic means of collecting complete profile surveys. As with the rod and transit method, sled surveys provide a shore normal profile typically spaced at about 30 - 300 m. Line spacings can be adjusted closer or farther apart depending on project data density requirements. However, as line spacing decreases, the total survey time and associated costs increase. Approximately 25 - 30 min are required to sample along a 300-m profile (Birkemeier 1994).

Performance Characteristics: (Clausner et al. 1986, Howd and Birkemeier 1987)

Vertical accuracy:	± 3 cm
Horizontal accuracy:	3 m (10 ft)
Spatial resolution:	Typically shore-normal lines 30 - 300 m (100-1,000 ft) apart
Positioning system:	ETS/Geodimeter relative to established benchmarks
Minimum crew:	2-3
Recent costs:	Approx. $4,500/km ($7,500/mile) of beach (assuming 300-m profile spacing)

Other Considerations: For projects that do not require a high degree of spatial resolution, sled survey methods provide a portable, low-cost means of acquiring accurate beach and nearshore survey data, including the surf zone. Sled surveys are often supplemented with traditional rod-based methods to capture irregular bathymetry. As with the rod and transit method, survey sleds may not produce adequate spatial resolution, which may introduce error during data interpretation or when conducting volumetric calculations. Survey sleds do not perform well on irregular bottoms or areas where rock or reef outcroppings are prominent. Such conditions can cause the sled to tip over or become snagged. Surveys can be conducted using this method in areas where the beach is easily accessible. Sleds have been shown to be stable in breaking waves up to 5 m (Sallenger et al. 1983); however, these instruments are typically towed by boat in the nearshore and should, therefore, be restricted to breaking waves 1 m or less (Dally 1993).

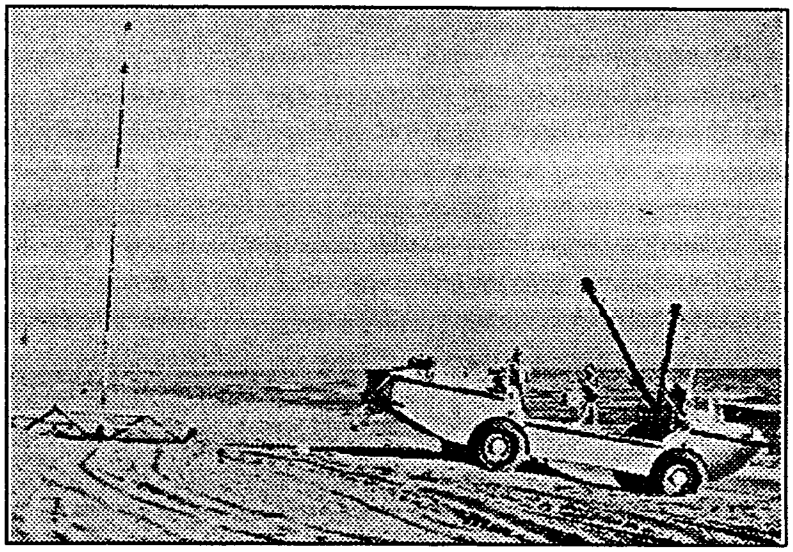

Figure 2. Sled profiling system (Clausner et al. 1986). Used to collect profile data through the surf zone and into the nearshore areas.

III. Single-Beam Fathometer

Description: Single-beam fathometer systems or echo sounders utilize sonar to acquire depths by measuring the time of travel of an acoustic pulse or "ping" between a transducer and the sea bottom as illustrated in Figure 3. Surveying using this technology is described by USACE (1994). Single-beam fathometers are

commonly used to survey the offshore portion of coastal projects in conjunction with beach profiles collected out to wading depth with attempts to overlap the two data sets. The extent of overlap and survey accuracy are highly dependent on the amount of wave action at the time of the survey. Fathometer soundings are a measure of water depth. Therefore, actions must be taken to correct for water level variations such as tides and waves, making it necessary to collect water level information at the time of the survey (Clausner et al. 1986). Accounting for water level fluctuations in the coastal zone is difficult and may have an effect on vertical accuracy. Motion compensation sensors can be utilized to isolate and remove some fluctuations due to vessel motion resulting from wave action (Dally 1993). Horizontal accuracies are highly dependent upon the type of positioning system used.

This technology has undergone major advances in recent years with the advent of sophisticated GPS technology, motion compensation sensors, and computerized data processing. Highly accurate three-dimensional positioning technology may eliminate the need for water level corrections. For more information on GPS positioning systems see Engineer Manual (EM) 1110-2-1003, "Hydrographic Surveying" (USACE 1994).

Performance Characteristics:

Vertical accuracy:	± 30 cm (1 ft)
Horizontal accuracy:	3 m
Spatial density:	30 - 300 m (nominal)
Platform:	Small boat
Positioning system:	Variable - ranging, Loran, GPS
Minimum crew:	2-3 (assuming a support person onshore)
Recent costs:	Approx. $1,000/km ($1,600/mile) of offshore portion of profile

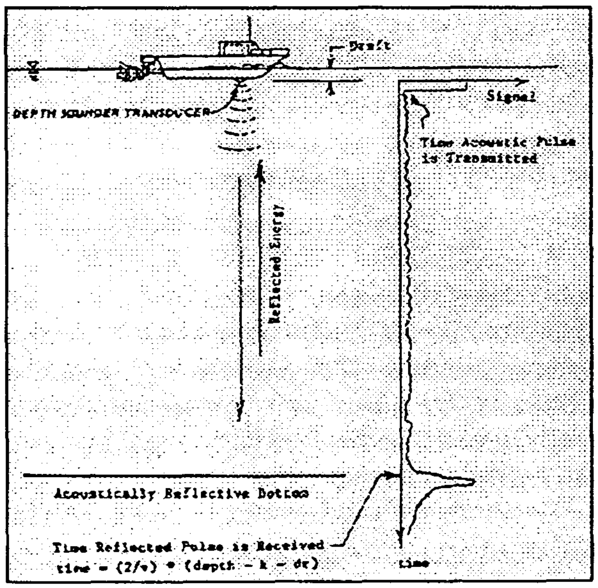

Figure 3. Single-beam fathometer commonly used to collect the submerged portion of beach surveys.

Other Considerations: Single-beam fathometer systems provide a fast, cost-effective method of extending beach surveys into the nearshore areas. The effects of wave motion may be difficult to remove, which may drastically decrease vertical accuracy . In most cases, overlapping the wading beach profiles with the fathometer portion of the survey is difficult and may lead to large gaps in the data. For this reason, it is best to conduct the wading profile at low tide and the fathometer portion at high tide (Clausner et al. 1986). Coordinating the survey times as such will maximize the opportunity for data overlap. Even when an overlap is achieved, water level fluctuations and platform motion may lead to closure problems.

IV. Multi-beam Fathometer

Description: In recent years there have been major advances in sonar technology for scanning pulse-based acoustic sensors that can be applied to coastal areas.

Expanding upon single-beam technology, multi-beam systems use multiple frequencies and receiving channels to collect soundings over a swath that can be four times as wide as the water depth. Echo sounders used with this type of technology are capable of utilizing 60 (+ or -) beams covering large corridors with each pass and literally providing 100 percent bottom coverage. Systems utilizing this technology are restricted to the offshore portions of the coastal zone. Used in conjunction with sophisticated positioning systems, they can provide an effective means of improving vertical and horizontal accuracies for collecting high-resolution bathymetry. Minimum depths are dependent upon the size of the platform used. In addition to the collection of nearshore bathymetry, some systems have the capability to laterally direct the echo sounding beam for surveying submerged coastal structures such as jetties, breakwaters, or groins. Related advances in motion compensation sensor technology have further added to the suitability of this method for use in the coastal environment (Mesa and Brooks 1994).

Performance Characteristics:

Vertical accuracy:	± 15 cm
Horizontal accuracy:	± 2 m
Minimum depth:	Platform dependent
Spatial density:	Up to 100%
Operating speed:	Platform dependent
Platform:	Boat
Positioning system:	GPS
Minimum crew:	3
Recent costs:	Approx. $2,000/km ($3,250/mile) full bottom coverage of offshore portion of beach

Other Considerations: Because multi-beam technology requires a boat platform, it is not suitable for extreme shallow-water applications and is subject to the same shortcomings as single-beam systems when used to supplement rod surveys. The shallower the water, the narrower the bottom coverage. Due to the multiple channel characteristics and to provide the spatial coverage, this technology generates high volume data sets. Data users should be prepared to handle large volume data sets or to account for data processing in the survey budget.

V. Airborne Lidar Bathymetry

Description: A state-of-the-art lidar system coupled with high precision GPS positioning is an emerging technology that can be utilized for conducting both hydrographic and topographic beach surveys. The term lidar stands for LIght Detection And Ranging. The SHOALS system shown here (Figure 4) operates by emitting laser pulses from an airborne platform that travel to the water surface. For each laser pulse, some of the light is reflected back from the surface to onboard receivers. The remaining energy propagates through the water column, reflects off the sea bottom, and returns to the airborne sensor. The time difference between the surface light return and the bottom return corresponds to water depth (Guenther et al. 1996). Maximum depth detection is limited predominately by water turbidity. As a rule of thumb, the system is capable of sensing depths equal to two or three times the visible depth (Estep et al. 1994). The laser is scanned in a 180-deg arc across the flight path of the helicopter, producing a swath width approximately one half the surveying altitude. At a speed of 60 knots and an altitude of 200 m, the system can provide a survey coverage of 9 km^2/hr. (Lillycrop et al. 1996). Sounding densities can be adjusted by flying higher or lower at different speeds or by selecting multiple scan widths. With the ability to collect both topographic and hydrographic survey data, this method can simultaneously conduct complete beach and structure surveys

above and below the waterline and could be particularly useful in areas where human access is difficult or restricted. The technology is a useful tool for post-storm erosion assessments. Data acquired using this type of technology can be used to generate vertical profiles, cross sections, contours, and volumetric analysis.

Performance Characteristics: (Lillycrop et al 1996)

Vertical accuracy:	± 15 cm
Horizontal accuracy:	± 3 m
Spatial density:	4-m grid (nominal)
Coverage:	9 km^2/hr (nominal)
	60 knots (nominal operating speed)
	200 Hz data aquisition rate
Platform:	Bell 212 helicopter
Positioning system:	GPS
Minimum crew:	5
Recent costs:	Approximately $1,800/km ($3,000/mile) of beach

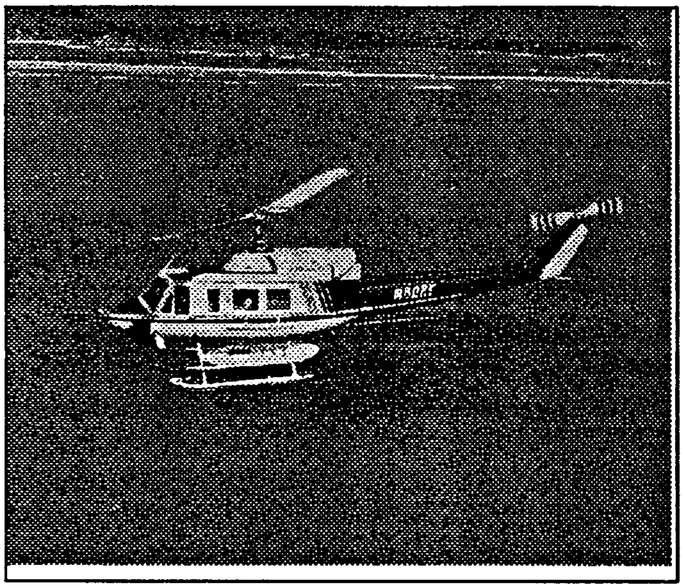

Figure 4. SHOALS Airborne lidar bathymetry and topographic system. Capable of providing high resolution surveys of the entire beach system, including associated structures.

Other Considerations: This technology is capable of rapidly collecting dense survey data over large areas in a short amount of time. However, the technology is highly dependent on water clarity and should not be considered for areas with chronic high turbidity. Costs pertaining to system mobilization can be high and may be a limiting factor when considered for surveying small projects. It is beneficial to schedule surveys along with other projects in the same general vicinity to share and minimize mobilization costs. Users of lidar survey data should possess data processing equipment and software capable of handling large data sets.

VI. Airborne Lidar Topography

Description: Other airborne lidar systems are available that are used exclusively for topographic applications. The system shown here (Figure 5) operates at 6,000 Hz, flies at a speed of 30 knots, and collects data over a wide swath. Its state-of-the-art kinematic OTF (On-The-fly) satellite positioning system allows for highly accurate three-dimensional geographic positioning. The system is small, inexpensive to operate, and produces high-resolution survey data for use in various mapping applications. Although not yet widely used in coastal areas, this type of technology could be useful for surveying subaerial beaches, dunes, and the above-water portions of coastal structures. As with other airborne sensors, this technology could be useful where direct access is difficult or restricted. The technology could prove useful for above-water storm damage assessments. Data acquired using this technology can be used to generate vertical profiles, cross sections, contours, and volumetric analysis.

Performance Characteristics:

Vertical accuracy:	± 5 cm
Horizontal accuracy:	± 10 cm
Spatial density:	0.5-m grid spacing
Coverage rate:	Approx. 5 km^2/hr
	30 knots (nominal) operating speed
	6,000 Hz data acquisition rate
Platform:	Small helicopter or fixed-wing aircraft
Positioning system:	GPS
Minimum crew:	2 (pilot and operator)
Recent costs:	Approx. $1,950/km ($3,250/mile) of dry beach

Other Considerations: This technology can only be used for topographic surveying. This instrument detects whatever is on or covering the ground. Care must be taken when collecting data near vegetation or other ground cover to assure that the data collected is what the user intends to survey. If hydrographic survey data are also required, this technology must be used in conjunction with other technologies. A high-resolution system such as this generates extremely large data sets. Data users should possess resources capable of handling large data files or be prepared to budget for data processing costs.

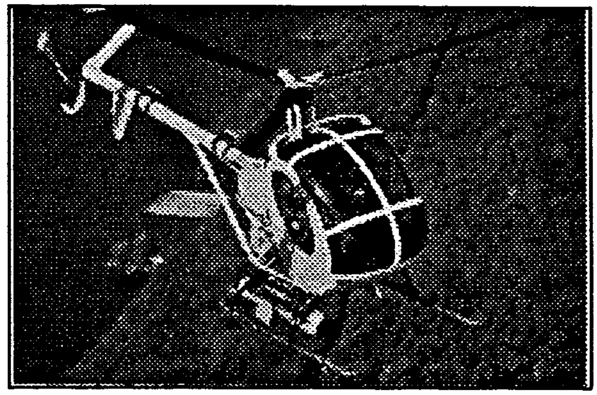

Figure 5. Airborne lidar topographic survey system. Used exclusively for topographic applications. The system shown here called FLI-MAP was developed by John E. Chance & Assoc.

VII. GPS Total Station Backpack

Description: Another alternative for the collection of detailed topographic information is through the use of a GPS total station (receiver and antenna) contained in a backpack and staff or mounted on a motorized vehicle such as an ATV. Differential GPS positioning (DGPS) for improved accuracy levels is possible but would require establishing a base station. This type of configuration permits rapid detailed digital elevation data to be collected on a continuous basis by walking or driving over the project survey area (Solomon 1996). Sample rates for collecting real-time positions are 0.5 - 1 sec. For normal walking rates, this translates to readings roughly every meter (3 ft) (Solomon 1996). Sampling intervals using a motorized vehicle would be greater depending upon the survey speed. Conventional profiling methods (rod and transit or sled) involve re-occupying a series of profiles marked by benchmarks, stakes, rebar, etc. Unfortunately, such benchmarks are frequently removed, buried, or obscured in some manner by natural processes or human activity. The GPS technique allows reestablishment of profile lines without multiple benchmarks as long as a single base station point is well-known. This capability can be extremely beneficial when surveying in areas where control data are deficient or absent such as in remote areas or in areas of severe storm damage. This system can also be useful for rapidly and cheaply mapping reference contours such as high-water lines, back beach and dune lines, etc.

Performance Characteristics:

Vertical accuracy:	15 cm or less (depending on GPS receiver)
Horizontal accuracy:	± 5 - 10 m
Data acquisition rate:	0.5- to 1.0-sec sampling rate
Spatial density:	1.0-m spacing depending upon operating speed
Operating speed:	Variable
Platform:	Backpack or suitable motorized vehicle (ATV)
Positioning system:	GPS/DGPS
Minimum crew:	2
Recent costs:	About $1,200/km ($2,000/mile) of beach, assuming 300-m profile spacing. May require processing costs.

Other Considerations: This method would be suitable only for conducting beach surveys extending to the low tide line or out to wading depth maximum. If hydrographic survey data are required through the surf zone and nearshore, this type of technology must be used in conjunction with other survey methods. As with any technology involving GPS positioning, problems may be encountered with unfavorable satellite configurations which may degrade positioning accuracies. In such instances, survey work should be coordinated during times of optimal satellite configurations. Most GPS systems provide software to facilitate this process (Solomon 1996).

ADDITIONAL INFORMATION

The information summarized in this Technical Note was gathered by the U.S. Army Engineer Waterways Experiment Station's (WES) Coastal and Hydraulic Laboratory (CHL) as part of the Surveying and Mapping Research and Development Program. The technologies and methods described in this Technical Note are not all-inclusive, but are intended to summarize methods that are most commonly used today for collecting beach and nearshore survey data as well as new demonstrated technologies that show promising potential for these applications. For additional information pertaining to the methods described here, please contact Mr. Larry Parson (voice: 334-690-3139; fax: 334-6903464; e-mail Larry.E.Parson@sam.usace.army.mil).

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